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INFLUENCE OF PLANTING DENSITY, INTENSIVE CULTURE, GEOGRAPHIC LOCATION, AND SPECIES ON JUVENILE WOOD FORMATION IN SOUTHERN PINE

by
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INTRODUCTION

Millions of acres of abandoned farmland and cut-over timber land have been planted with southern pine in the South and these plantations will increasingly become the mainstay of the softwood timber supply. Wood from these fast-growing plantations often has physical and mechanical properties that make it less desirable than wood from older, natural stands because plantation trees contain more juvenile wood. Building products containing juvenile wood are weaker and more prone to warp, creating problems for manufacturers and consumers. The adverse effects of juvenile wood on product quality and yield are of great concern to manufacturers of lumber, plywood, composites, and paper. Timberland owners have equal concerns and need to know the factors associated with juvenile wood formation and wood properties.

The objective of this paper is to define juvenile wood and how silvicultural practices, geographic location and species influence juvenile wood formation. The silvicultural practices examined include initial planting density, cultivation and fertilization. Juvenile wood formation is examined in loblolly, slash and longleaf pine.

JUVENILE WOOD:
How it is formed and what are its properties

A radial cross-section of a pine stem contains three zones of wood (fig. 1): 1) core or crown-formed wood produced by immature cambium in the vigorous crown, which has anatomical, chemical, and physical properties substantially different from mature wood; 2) transition wood, which is in a zone where wood properties are changing rapidly before reaching maturity; and 3) mature wood. In the spring, radial growth begins at the apex of the bole in the vigorous crown (Wareing 1958, Zahner 1963) which accounts for the preponderance of thin-walled earlywood cells and wider rings in the upper bole than in the lower bole. The transition to thick-walled latewood tracheids occurs first near the base of the bole, farthest from the source of auxins, and proceeds upward as the moisture stress increases and translocation of auxins down the bole decreases (Zahner 1963, Larson 1969). As trees grow older and taller and stands close, lower branches cease to be vigorous, and the lower portion of active crown moves up the stem. Therefore, there is a core

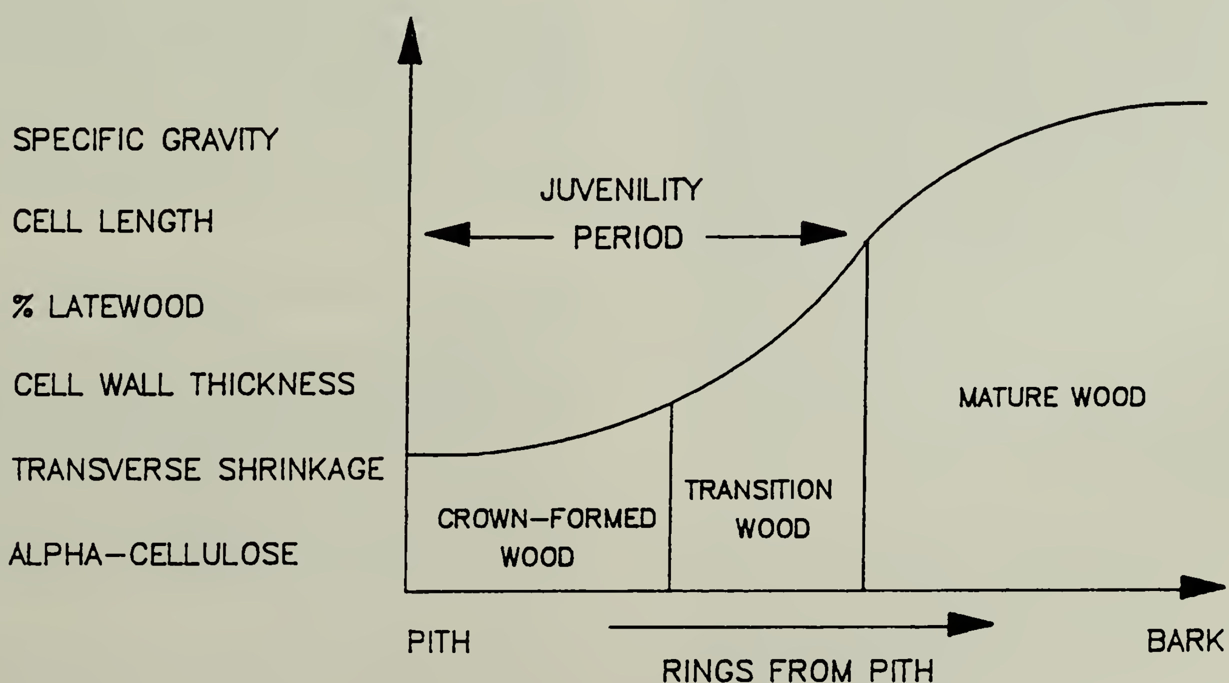


Figure 1. Diagram of a radial cross section of a pine stem showing three zones of wood and how wood properties change with age (rings) from the pith.

of crown-formed wood surrounded by a band of transition wood from the butt to the merchantable top of the tree (Paul 1957, Zobel et al. 1959) (fig. 2). Both crown-formed and transition wood are commonly referred to as juvenile wood.

The size of the juvenile core is related to the rate of growth, which is influenced by initial spacing and the period to crown closure. Using growth and yield simulation, Martin (1984) shows that the proportion of bole wood composed of juvenile wood is highly influenced by initial spacing. He reports that trees planted 7 by 7 feet, thinned at ages 16 and 27, and harvested at age 35 will have aproximately the same average d.b.h. as trees planted 12 by 12 feet, not thinned, and harvested at age 35, but the former trees will have only 31 percent of their boles in juvenile wood compared to 51 percent for the unthinned 12 by 12 trees. Zobel and Blair (1976) reported the proportion of juvenile wood in the merchantable bole on a dry weight basis to be 76 percent for 15-year-old stands, 50 percent for 25-year-old stands, and only 15 percent for 40-year-old stands.

The properties of juvenile wood and their adverse effects on product quality and yield have been reported by many researchers (Thomas 1984, Megraw 1985, Zobel 1981, Bendtsen 1978, Bendtsen 1987, Senft et al. 1986). Crown-formed wood tracheids are shorter and thinner walled with larger lumens than mature-wood tracheids, and crown-formed wood contains a smaller proportion of latewood tracheids than wood formed below the crown. Since the proportion of earlywood and latewood are the major determinants of specific gravity, the specific gravity of mature wood is 15 to 30 percent greater than that of juvenile wood. Wood from young fast-growing plantations containing a high proportion of juvenile wood will yield less pulp per green ton than wood containing a lower proportion of juvenile wood.

In addition to low specific gravity, juvenile wood has tracheids that are shorter and have larger fibril angles than those in mature wood. These tracheid properties cause juvenile wood to have strength and shrinkage properties that are inferior to those of mature wood. Based on recent studies of the influence of juvenile wood on the strength properties of dimension lumber of southern pine (MacPeak et al. 1990, Pearson 1988), it appears that lumber cut from the juvenile zone of young fast-grown plantation pine will not meet design requirements. In the MacPeak et al. study, 2 by 4's cut from 20- and 50-year-old plantation slash pine trees averaging 14.3 and 15.1 inches d.b.h., respectively, were tested to failure in bending. The ratios of average properties for the 20-year plantations to those of the 50-year-old plantations were 0.54 for modulus of elasticity and 0.45 for modulus of rupture. Franklin (1987) predicts that buyers will pay less for saw logs from plantations than from natural stands because of their high juvenile wood content.

Researchers have found specific gravity and tracheid length of juvenile wood to be under moderate genetic control (Loo et al. 1985, Zobel and Talbert 1984, Matziris and Zobel 1973, Zobel et al. 1978). Loo and others also report that the length of juvenility is genetically inherited. Genetic influence is implied when species such as loblolly *(Pinus taeda* L.) and slash *(P. elliotti Englem)* pine are compared. Based on the literature, loblolly has a juvenility period of 9 to 12 years, (Pearson and Gilmore 1980, Zobel and McElwee 1958) while slash has an average juvenility

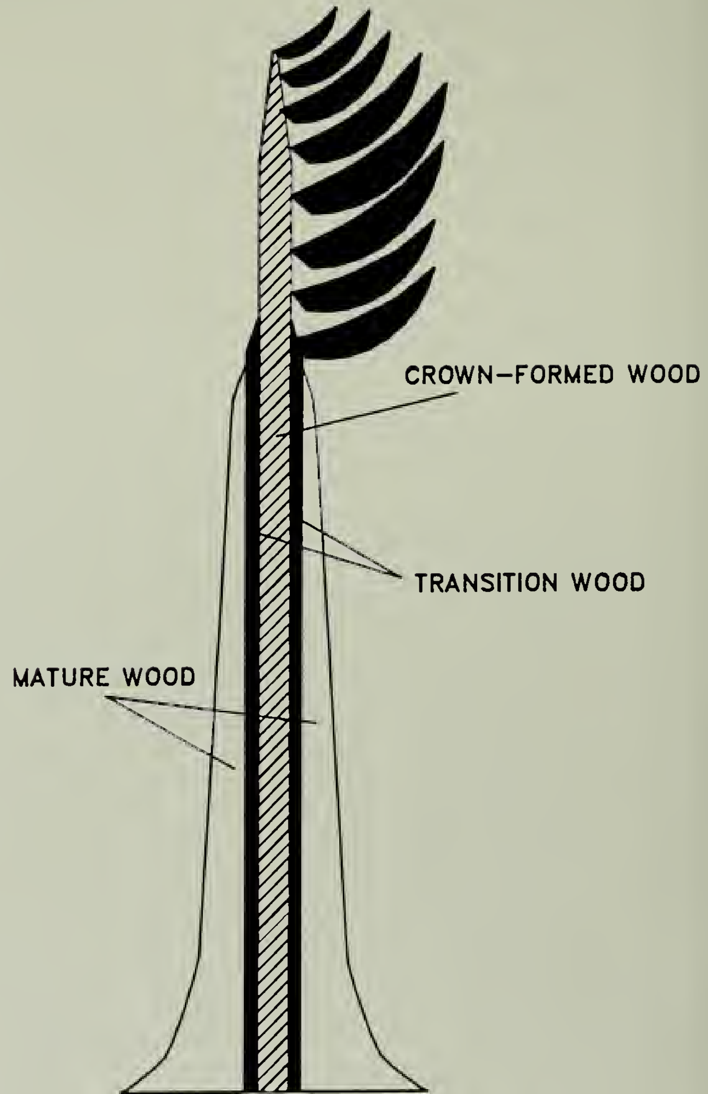


Figure 2. Schematic diagram showing core of crown-formed wood surrounded by band of transition wood and mature wood in standing tree.

period of 6 to 8 years (Taras 1965, Larson 1969, Zobel and Talbert 1984).

The objectives of the studies reported here were: 1) determine the effect of initial planting densities on the length of juvenility from juvenile to mature wood and the proportional volume of juvenile wood at breast height, 2) examine wood formation of planted slash and loblolly pines grown under the same environmental conditions to determine if species differences exist, 3) examine how the length of juvenility varies with geographic location, and 4) determine the effect of cultivation and fertilization on juvenile wood formation.

Annual rings can be classed as crown-formed, transition, or mature wood on the basis of cell structure and the proportions of earlywood and latewood tracheids. These factors determine or correlate with the average specific gravity of the ring. In this paper, specific gravity is used to separate juvenile and mature wood.

PROCEDURE

Field

To examine the effect of initial planting density on length of juvenility, plantations from two separate spacing studies were sampled. A slash pine study established in 1952 on the Holt Walton Experimental Forest on the Upper Coastal Plain of Georgia in Dooly County (Jones 1986) and a loblolly pine study established in 1957 on the Calhoun Experimental Forest on the Piedmont of South Carolina in Union County (Balmer et al. 1975, Harms and Lloyd 1981) serve as the study material. The slash pine plots with spacings of 6 by 6, 8 by 8, 10 by 10, and 15 by 15 feet were sampled. Two 2 mm increment cores were removed at breast height from each of 15 randomly selected trees from eah plot. The study was replicated twice. The loblolly pine plots with spacings of 6 by 6, 8 by 8, 10 by 10, and 12 by 12 feet were sampled. Two increment cores were removed from each of 10 randomly selected trees from each plot. The loblolly study was replicated four times.

To examine length of juvenility associated with species and with geographic location, eight other plantations were sampled. Five of these plantations contained both loblolly and slash pine either interplanted or planted adjacent to each other at locations extending from the Piedmont of South Carolina to northwest Florida. Plantations sampled in North Carolina and Virginia contained only loblolly pine but were sampled to expand the range of our sample for examining the associated difference in juvenility with geographic location in this species. At all locations and for each species, two 12 mm increment cores were removed at breast height from 30 randomly selected trees.

To examine the effects of cultivation and cultivation plus fertilization on juvenile wood formation, a plantation established in 1960 on the Gulf Coastal Plain in Harrison County, Mississippi, was sampled (Schmidtling 1973). The study site had been stocked with second-growth longleaf pine before being clearcut in 1958-59.

In February and March 1960, 1-year-old loblolly, slash, and longleaf seedlings were bar-planted at 10 by 10-foot spacings. The study design was a split plot with four replications. Main plots were species, and completely randomized within each main plot were five cultural treatments. The cultural treatments applied in the study were:

Abbreviation	Treatment
C	Control, no cultivation or fertilization
T-0	Cultivation with no fertilization
T-1	Cultivation and a single application of 1000 lbs 10-5-5 NPK/acre
T-2	Cultivation and a single application of 2000 lbs 10-5-5 NPK/acre
T-4	Cultivation and a single application of 4000 lbs 10-5-5 NPK/acre

Stumps, soil, and competing vegetation were not disturbed on the control plots but cultivated plots were cleared of all stumps and slash and then plowed and disked. Cultivation consisted of disking three times each season for 3 years after planting and mowing in the fourth and fifth seasons. Fertilizer was distributed with an agricultural spreader and disked into the soil in May 1961, 1 year after planting.

In the original study the plantation was established with open-pollenated seed from parent trees with high specific gravity and average specific gravity for each species. The low selection differential in the parent population did not result in large enough differences in specific gravity of the progeny to draw conclusions concerning these effects. Thus, only the treatment effects on the average specific gravity progeny are reported in this paper.

In the winter of 1985, 25 years after planting, the d.b.h. and total height of all surviving measurement trees were recorded. Two increment cores, 2 mm in diameter were removed at breast height from each of 5 randomly selected trees from each subplot for a total of 20 trees per treatment and 100 trees per species. Figure 3 shows the location of all plantations sampled. Means and ranges of physical dimension of sample trees are shown in Table 1.

Laboratory

In the laboratory one increment core from each tree was separated into 2-year segments from the pith to and including the 20th ring. The unextracted specific gravity of each 2-year segment was determined based on green volume and ovendry weight. Specific gravity of the remainder of the increment core was also determined and included with the segments defined as mature wood. The second core from each tree was used to determine the width of earlywood and latewood. Each ring was measured to the nearest 0.001 mm with a microscope.

Specific gravities of the juvenile wood and mature wood zones were determined by weighting segment specific gravity and the specific gravity of rings 21 to bark in proportion to their incremental basal area. The age at which transition from juvenile to mature wood occurred was estimated based on visual examination of plots of ring specific gravity over rings from pith. An analysis of variance and Duncan's Multiple Range Test were performed to determine whether treatment significantly affected

Table 1.--Means and range of sample tree measurements by study, location, and species.

Species	Cultural treatment1/	Trees: Spacing	Trees: Sampled	Trees: Age	Average d.b.h.	Average total height
		-Feet-	-Number-	Years	-Inches-	--Feet---
			Effect of Spacing			
			South Carolina Piedmont			
Loblolly	None	6X6	40	30	8.0	68
		8X8	40	30	9.0	71
		10X10	40	30	9.7	71
		12X12	40	30	11.3	73
			Georgia Coastal Plain			
Slash	None	6X6	30	35	7.3	60
		8X8	30	35	8.9	71
		10X10	30	35	10.7	74
		15X15	30	35	12.9	76
			Species Comparison			
			South Carolina Piedmont			
Loblolly	None	8X8	30	27	9.5	70
Slash		8X8	30	27	9.8	69
			South Carolina Coastal Plain			
Loblolly	None	8X8	30	31	10.1	69
Slash		8X8	30	31	10.3	73
			Georgia Coastal Plain			
Loblolly	None	8X8	60	31	10.6	72
Slash		8X8	55	31	10.1	71
			Florida Coastal Plain			
Loblolly	None	6X9	30	24	8.8	62
Slash		6X9	30	24	8.1	62
			Effect of Geographic Location			
			Virginia Piedmont			
Loblolly	None	6X10	30	29	9.7	62
			North Carolina Piedmont			
Loblolly	None	6X10	30	28	9.4	66
			North Carolina Coastal Plain			
Loblolly	None	6X10	30	26	9.8	65
			Effect of Cultivation and Fertilization			
Loblolly	Control	10X10	20	25	6.0	40
	Cultivation + No NPK	10X10	20	25	6.3	44
	Cultivation + Low NPK	10X10	20	25	8.9	60
	Cultivation + Med NPK	10X10	20	25	9.3	62
	Cultivation + High NPK	10X10	20	25	10.1	68
Slash	Control	10X10	20	25	6.7	50
	Cultivation + No NPK	10X10	20	25	6.8	53
	Cultivation + Low NPK	10X10	20	25	8.4	59
	Cultivation +Med NPK	10X10	20	25	8.8	62
	Cultivation + High NPK	10X10	20	25	9.3	63
Longleaf	Control	10X10	20	25	7.3	55
	Cultivation + No NPK	10X10	20	25	6.1	48
	Cultivation +Low NPK	10X10	20	25	8.1	59
	Cultivation + Med NPK	10X10	20	25	8.8	60
	Cultivation + High NPK	10X10	20	25	8.6	61

1/ Low NPK = 1,000 lbs 10-5-5 per acre
Med NPK = 2,000 lbs 10-5-5 per acre
High NPK = 4,000 10-5-5 per acre

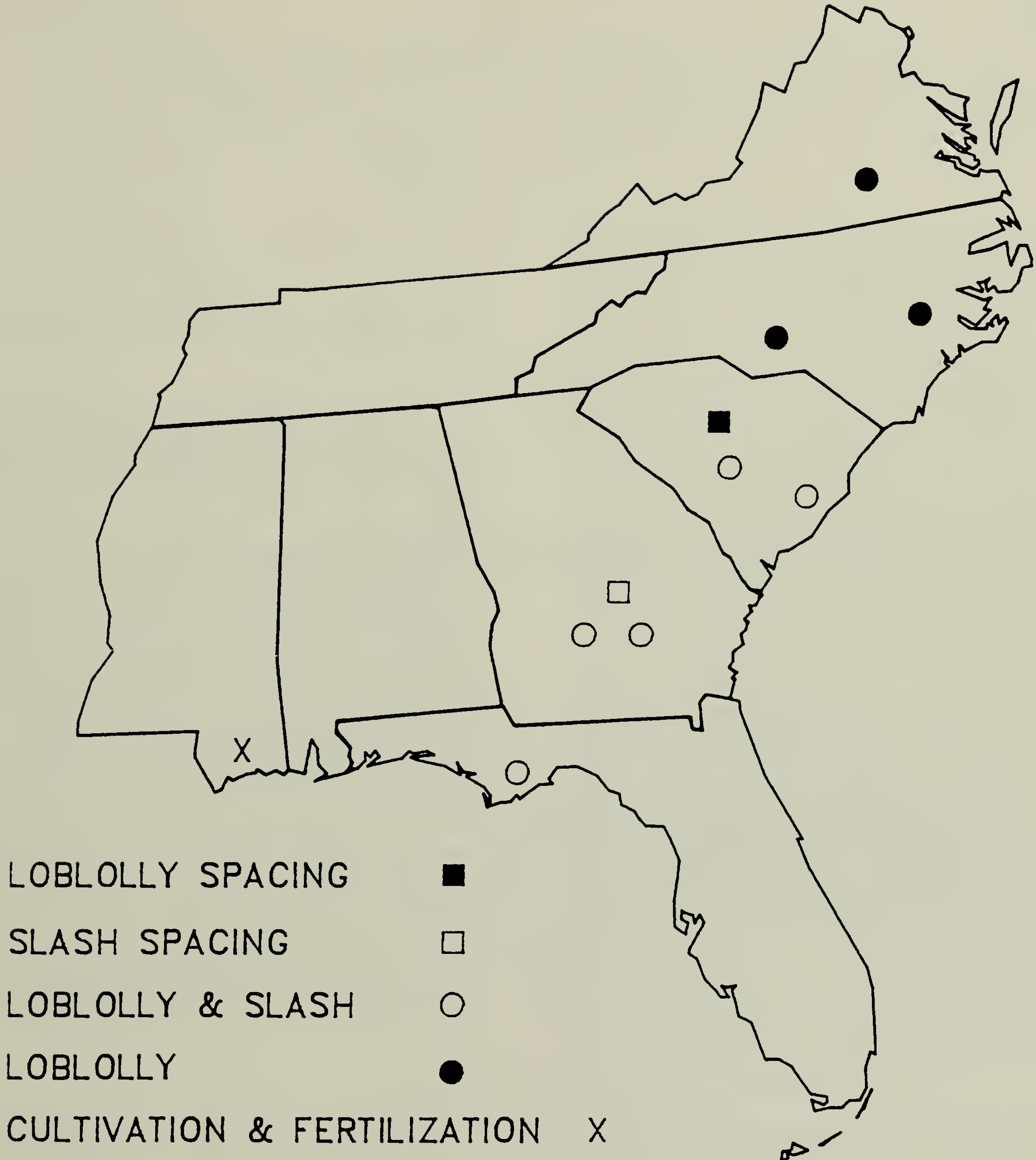


Figure 3. Location of plantations sampled for evaluating the effect of initial planting density, geographic location, and species intensive culture on juvenile wood formation of southern pine species.

specific gravity of juvenile wood, mature wood, or the combined zones at the P=0.05 percent level. An analysis of variance and Duncan's Multiple Range Test were also performed to determine if the specific gravity of loblolly and slash pine differ significantly when growing at the same location.

The loblolly and slash pines sampled from the two plantations in Dooly County, Georgia, were combined by species as a single location after analysis of the data showed no significant difference in the juvenility period or wood specific gravity.

RESULTS

Graphic plots of average 2-year specific gravity data over rings from pith for each spacing show that slash pine in the upper Coastal Plain of Georgia (fig. 4) produced juvenile wood for the first 10 rings for all spacings sampled. Wood produced in the 2-year segments after the 10th year has mature wood qualities. The diameter of the juvenile wood zone was significantly related to initial spacing and averaged 4.0 inches in trees spaced 6 by 6 feet, 4.6 inches in trees spaced 8 by 8 feet, 5.5 inches in trees spaced 10 by 10 feet, and 6.3 inches in trees spaced 15 by 15 feet.

Although the point of transition to mature wood is less clear, loblolly pine in the Piedmont (fig. 5) has a longer and more gradual juvenile transition period up to and including the 14th ring, after which mature wood is produced. The diameter of the juvenile wood zone in loblolly averaged 5.2 inches in trees spaced 6 by 6 feet, 6.0 inches in trees spaced 8 by 8 feet, 6.6 inches in trees spaced 10 by 10 feet, and 7.7 inches in trees spaced 12 by 12 feet.

Spacing did influence wood specific gravity during plantation development. In the early years, before stand closure, trees at wider spacing on the average had higher wood specific gravity; after stand closure, the reverse was true. For example, the specific gravity of juvenile wood produced in the first eight rings from pith of slash pine was highest at wider spacing, but the trend reversed in the later development of the plantation (fig. 4). A similar, but less pronounced, trend is found in loblolly pine (fig. 5). A possible explanation for these trends is that young trees growing at wide spacings have less competition for site resources and thus produce more photosynthate and denser earlywood than trees at closer spacing. As the stands develop, specific gravity becomes more strongly influenced by the proportions of earlywood and latewood tissues produced. Wider-spaced trees tend to produce larger percentages of earlywood, thus, the trends reverse.

Spacing did influence specific gravity (figs. 4 and 5) but statistical analysis indicates that the only statistically significant difference occurred in slash pine mature wood specific gravity between the 6 by 6-foot and 15 by 15-foot spacings (table 2). The persistent crowns of slash planted at 15 by 15-foot spacing and of loblolly planted at 12 by 12-foot spacing delayed the transition from earlywood to latewood during the growing season at the height levels sampled. Thus, trees at the wider spacing contained less latewood on a percentage basis and lower specific gravity.

Several studies in the literature indicate that the period of juvenility in slash and loblolly pine differ--loblolly 9 to 12 years, slash 6 to 8 years. (Larson 1969, Pearson and Gilmore 1980, Taras 1965). The results of our study show that the period of juvenility of slash and loblolly pine is less

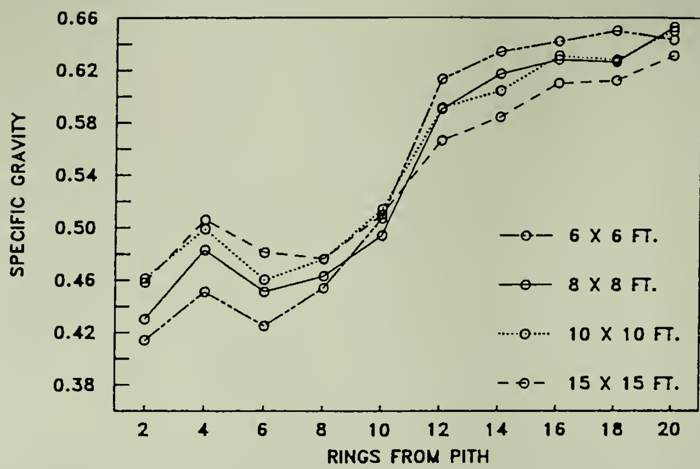


Figure 4. Influence of spacing on wood specific gravity at breast height of slash pine planted in the Upper Coastal Plain of Georgia.

influenced by inherent species differences than by environmental differences associated with geographic location. When these species are grown in the same or neighboring plantations, they display the same juvenility pattern when measured by wood specific gravity changes.

Figure 6 shows specific gravity trends for the two species at four different locations ranging from the Piedmont of South Carolina to the Gulf Coastal Plain of Florida. At each location, the pattern of juvenility is similar for both species. In the Piedmont of South Carolina, both species produced juvenile wood for the first 14 rings from pith; 10 years in the Coastal Plain of Georgia and South Carolina; and 6 years in the Gulf Coastal Plain of Florida.

The influence of geographic location on length of juvenility and wood specific gravity in loblolly and slash pines is shown in Figure 7. The plots of loblolly specific gravity over rings from pith show two groups of curves--one for the Piedmont locations and one for the Coastal Plain locations. As a group, loblolly pine sampled in the Coastal Plain produced juvenile wood for the first 6 to 10 rings while loblolly pine sampled in the Piedmont produced juvenile wood for about the first 10 to 14 rings.

The length of juvenility of slash pine also varied with geographic location (fig. 7). In these data, the distinctions

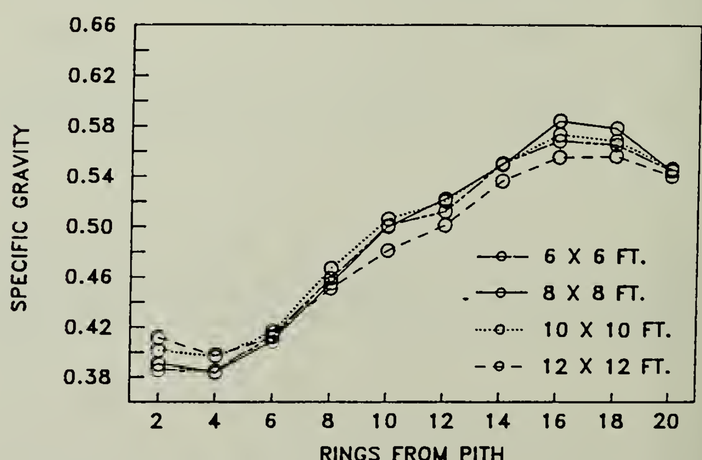


Figure 5. Influence of spacing on wood specific gravity at breast height of loblolly pine planted in the Piedmont of South Carolina.

Table 2.--Effect of spacing on weighted specific gravity at breast height of loblolly and slash pine juvenile wood, mature wood.

Spacing	Weighted specific gravity		
	Juvenile wood	Mature wood	All wood
Feet			
	Piedmont Loblolly Pine		
6 X 6	0.42 a 1/	0.55 a	0.46 a
8 X 8	.43 a	.56 a	.46 a
10 X 10	.44 a	.55 a	.47 a
12 X 12	.43 a	.54 a	.47 a
	Upper Coastal Plain Slash Pine		
6 X 6	.45 a	.63 a	.51 a
8 X 8	.46 a	.62 a b	.52 a
10 X 10	.49 a	.62 a b	.54 a
15 X 15	.50 a	.60 b	.54 a

1/ Values with the same letter do not differ significantly at the 0.05 level according to Duncan's Multiple Range Test.

Table 3.--Effect of intensive cultivation and species on weighted specific gravity of juvenile, mature and all wood (juvenile and mature combined).

Species	Treatment 1/				
	Control	Cultivation + No NPK	Cultivation + Low NPK	Cultivation + Med NPK	Cultivation + High NPK
	Specific gravity				
			Juvenile Wood		
Loblolly	.44	.46	.44	.45	.44
Slash	.51	.51	.49	.50	.50
Longleaf	.50	.54	.51	.50	.50
			Mature Wood		
Loblolly	.58	.59	.60	.61	.60
Slash	.60	.62	.62	.63	.62
Longleaf	.60	.62	.62	.60	.62
			All Wood		
Loblolly	.50	.51	.51	.53	.51
Slash	.57	.57	.56	.57	.56
Longleaf	.57	.58	.56	.55	.55

1/ Low NPK = 1,000 lbs 10-5-5 per acre
Med NPK = 2,000 lbs 10-5-5 per acre
High NPK = 4,000 lbs 10-5-5 per acre

between locations is clearer. In Florida, slash pine produced juvenile wood for the first 6 years, 10 to 12 years in the Coastal Plain of South Carolina and Georgia, and 14 years in the Piedmont of South Carolina.

Two factors which influence the proportion of tree basal area in juvenile wood at harvest are: 1) the tree's age at harvest and 2) the geographic location where the tree is growing. The influence of tree age and geographic location on proportion of basal area in juvenile wood are illustrated in Figure 8. As a tree grows older the proportion of its basal area in juvenile wood decreases. After age 6, trees growing in the Gulf Coastal Plain have proportionally less basal area in juvenile wood at breast height than trees in the Atlantic Coastal Plain and the Piedmont.

The trees sampled in the cultivation and fertilization study on the Gulf Coastal Plain in Mississippi displayed a dramatic increase in d.b.h. and total height growth with increased cultural treatment (table 1). Mean d.b.h., averaged across species, was 6.7 for the control, 6.4 inches for the cultivation only, 8.5 inches for the cultivation and low level fertilization, 9.0 inches for the cultivation and medium level fertilization, and 9.3 inches for the cultivation and high-level fertilization. Trees of all species on the cultivation plus high fertilization plots were significantly larger than the trees on the control or cultivation only plots.

Plottings of specific gravity over rings from the pith (fig. 9) show that cultivation plus fertilization reduced annual ring specific gravity of longleaf pine during the first 8 to 10 years after fertilization and increased its length of juvenility. Cultural treatments, however, had no significant influence on ring specific gravity or length of juvenility of loblolly or slash pine. Based on Figure 9, the length of juvenility was estimated to be 6 years for the control longleaf compared to 10 years for the cultivated and cultivated plus fertilized longleaf trees. Length of juvenility averaged 8 years for loblolly and slash control and treatment trees.

Cultivation and cultivation plus fertilization did not significantly affect the average weighted specific gravity of juvenile or mature wood (table 3). Weighted specific gravity of juvenile and mature wood combined was significantly lower for loblolly pine compared to slash or longleaf. Weighted specific gravity of loblolly across cultural treatments averaged 0.51 compared to 0.57 for slash and 0.56 for longleaf. These differences are due to differences in juvenile wood specific gravity.

At age 25, the basal area per acre of the cultivation plus fertilization plots was greater than that of the controls for all species (fig. 10). Cultivation only significantly increased basal area per acre of longleaf pine because of improved survival. On the cultivation plus low level fertilization plots, longleaf and slash pine had about the same basal area per acre but slash contained 10 percent less juvenile wood. Longleaf and loblolly produced more basal area per acre on the cultivated plus medium and high level fertilization plots than slash. However, the slash contained on the average 16 percent less juvenile wood.

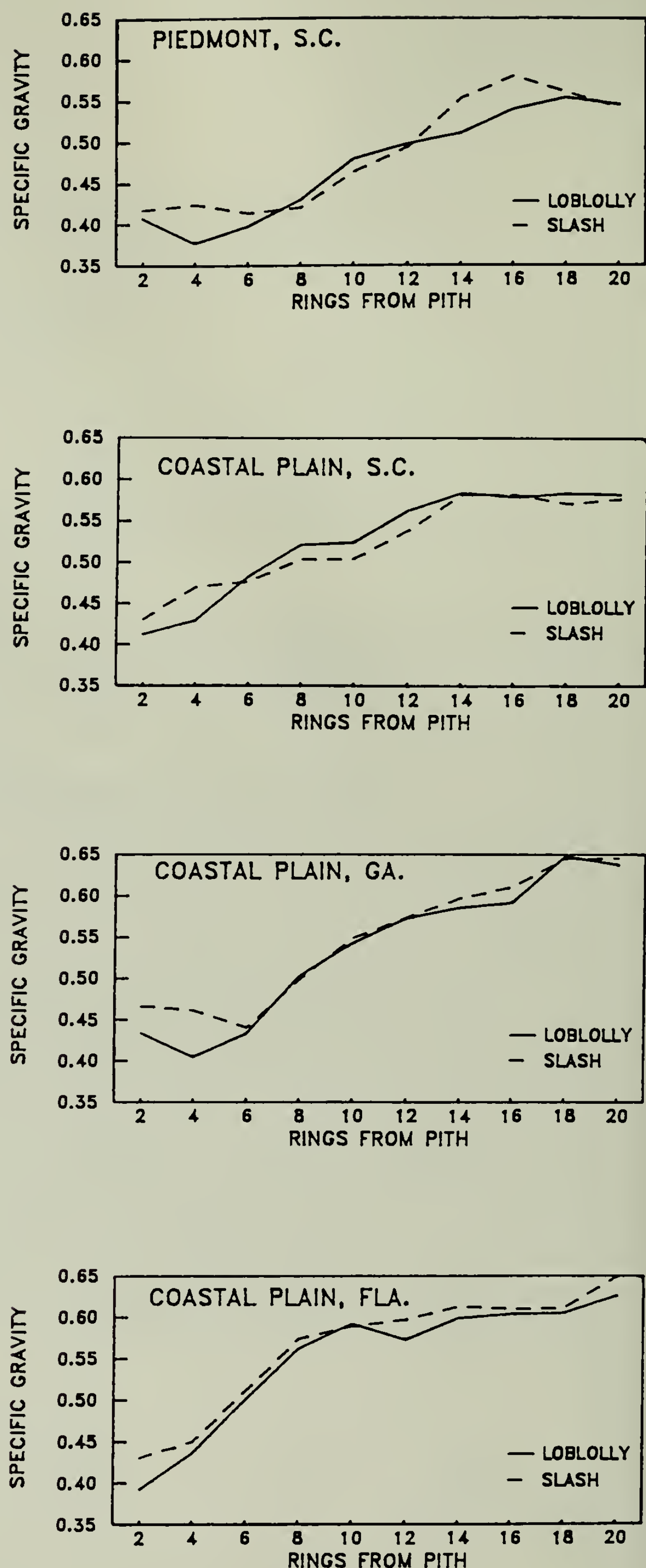
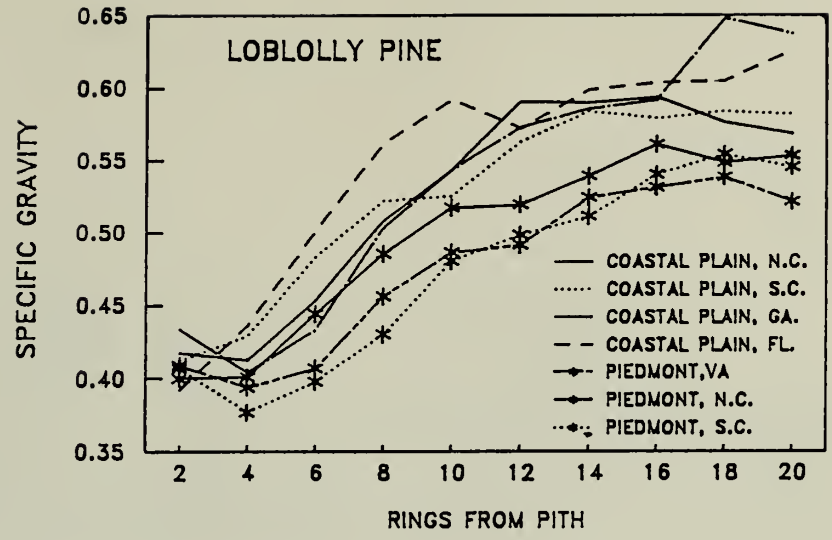


Figure 6. Comparison of ring specific gravity for slash and loblolly pine growing together at four different locations.



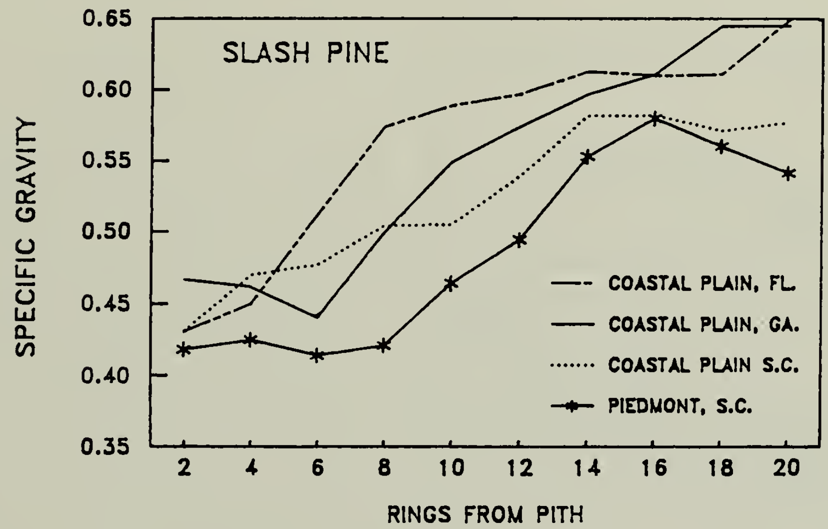


Figure 7. Influence of geographic location on ring specific gravity and length of juvenility for loblolly and slash pine.

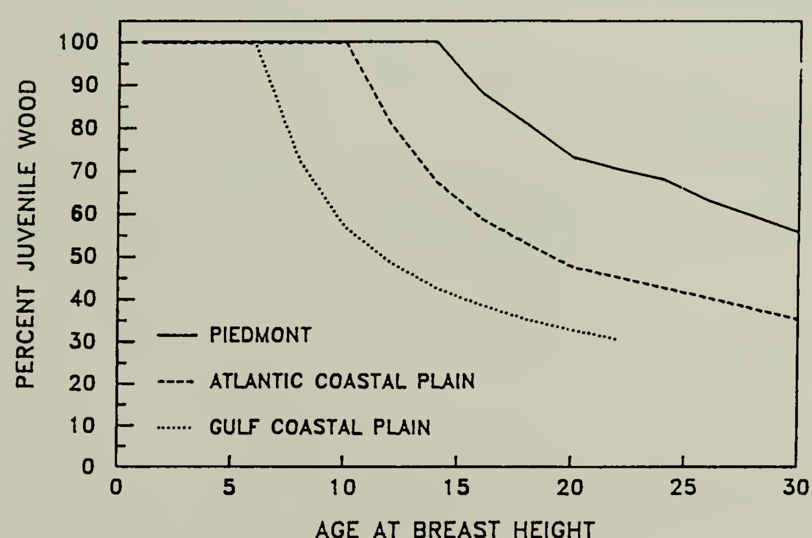


Figure 8. Influence of geographic location and age at breast height on proportion of stemwood basal area in juvenile wood of loblolly pine.

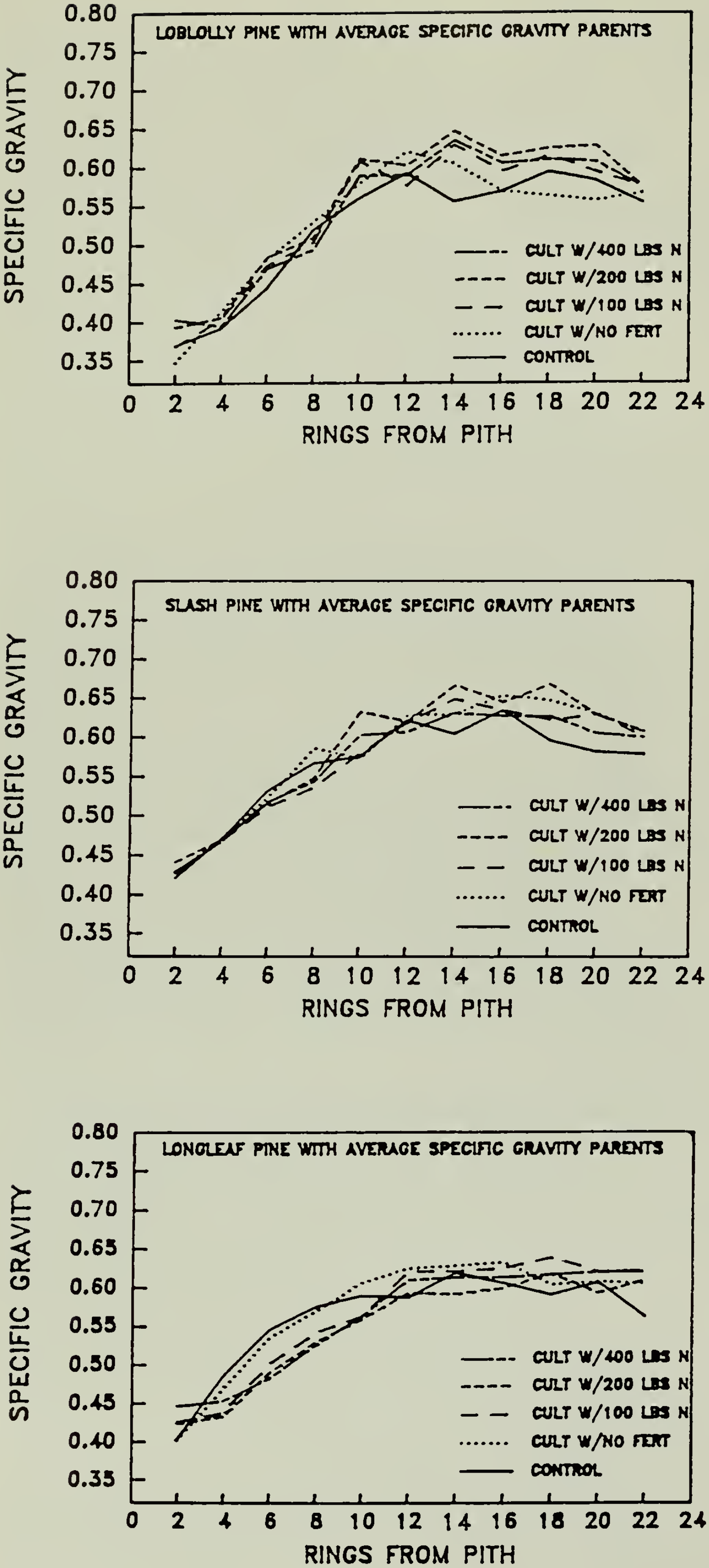


Figure 9. Effect of intensive cultural treatment on ring specific gravity and length of juvenility for loblolly, slash, and longleaf pine.

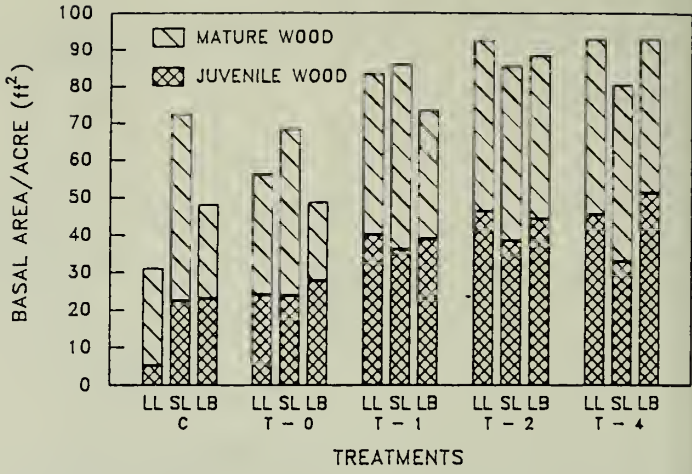


Figure 10. Influence of intensive culture on basal area per acre in juvenile and mature wood by species.

SUMMARY AND DISCUSSION

The results of this study show that the number of years a tree produces juvenile wood at a given height level in the tree is not significantly influenced by initial planting density but is highly correlated with geographic location. Loblolly pine planted in the Piedmont at spacings ranging from 6 by 6 to 12 by 12 feet had a juvenility period of 14 years while slash pine planted in the Upper Coastal Plain at spacings ranging from 6 by 6 to 15 by 15 had a juvenility period of 10 years for all spacings sampled.

The length of the juvenile period of slash and loblolly pine decreased geographically from north to south. In loblolly and slash pine the period of juvenile wood formation decreased from 14 years in the Piedmont to 6 years in the Gulf Coastal Plain.

Loblolly and slash pine growing in the same or neighboring plantation at four geographic locations displayed the same juvenile patterns within locations. Reported differences in length of the juvenile period in these species is largely due to geographic differences, not species differences.

The variation in length of juvenility with geographic location appears to be related to the climatic factors of temperature (length of growing season) and seasonal rainfall patterns. Zahner (1963) hypothesized that when soil moisture is plentiful cell division and maturation are rapid and there is severe competition for carbohydrates and auxins among newly formed cells. Under these conditions the cambium is better able to compete for these materials than maturing tracheids. Thus, the maturing tracheids die and become part of the earlywood. When soil moisture is scarce (moisture stress high), cambial activity is reduced, maturing tracheids can compete more successfully for available carbohydrates, wall thickening occurs, and latewood is produced.

Cregg et al. (1988) observed that the transition from earlywood to latewood occurred one month earlier in a year of low rainfall and high spring evaporative demand than in a year of low evaporative demand and high rainfall. In the Coastal Plain the transition from earlywood to latewood may occur earlier than in the Piedmont because of the earlier arrival of hotter summer weather. However, the Coastal Plain region usually receives moisture sufficient for latewood production in summer showers. In the Piedmont, however, moisture often becomes a limiting factor because of fewer summer showers and latewood production not only starts later in the growing season but also stops sooner because of severe moisture stress.

When nutrients, rather than moisture, are the limiting growth factor, as occurred on the poor sandy-loom site sampled on the Gulf Coastal Plain, cultivation plus fertilization significantly increased growth but did not effect the length of the juvenility period of loblolly or slash pine. Cultivation plus fertilization did, however, increase the length of juvenility of longleaf pine. Cultivation and fertilization had no significant effect on juvenile or mature wood specific gravity.

This study shows that although the juvenile period is not altered, planting density can be used to influence the size of the juvenile core by controlling radial growth. By planting close and thinning after the trees are producing mature wood, resource managers can minimize the diameter of the juvenile core and reduce branch knot size. Managers can also reduce the proportion of juvenile wood harvested and increase the proportion of clear mature wood by lengthening rotation age. Further research is needed to determine optimum spacing, thinning and rotation lengths for producing high value trees for production of quality lumber and veneer.

LITERATURE CITED

Balmer, W.E.; Owens, E. G.; Jorgensen, J. R. 1975. Effects of various spacings on loblolly pine growth 15 years after planting. Res. Note SE-211. Asheville, NC: U. S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 7 pp.

Bendtsen, B. Alan. 1978. Properties of wood from improved and intensively managed trees. Forest Products Journal 28(10):6-1-72.

Bendtsen, B. A. 1987. Quality impacts of the changing timber resource on solid wood products. Proc. 47349 pp. 44-57. In: Managing and Marketing the Changing Timber Resource; 1986 March 18-20; Fort Worth, TX. Madison, WI: Forest Products Research Society.

Cregg, B. M.; Dougherty, P. M.; Hennessey, T. C. 1988. Growth and wood quality of young loblolly pine trees in relation to stand density and climatic factors. Canadian Journal of Forest Research 18(7): 851-858.

Franklin, E.C. 1987. Economics of forest management options: influence on wood properties. TAPPI 70(1): 85-88.

Harms, W. R.; Lloyd, F. T. 1981. Stand Structure and Yield Relationships in a 20-Year-Old Loblolly Pine Spacing Study. Southern Journal of Applied Forestry 5:162-166.

Jones, E. P., Jr. 1986. Slash pine plantation spacing study--age 30. In: Phillips, D. R., ed. Proceedings of the 4th biennial southern silvicultural research conference; 1986 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U. S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. pp. 45-49.

Larson, P. R. 1969. Wood formation and the concept of wood quality. Bull. No. 74. New Haven, CT: Yale University, School of Forestry. 54 pp.

Loo, J. A.; Tauer, C. G.; McNew, R. W. 1985. Genetic variation in the time of transition from juvenile to mature wood in loblolly pine *(Pinus taeda* L.). Silvae Genetica 34(1): 14-19.

MacPeak, Malcom D.; Burkhart, Leonard F.; Weldon, DeWayne. 1990. Comparison of grade, yield, and mechanical properties of lumber produced from young fast-grown and older slow-grown planted slash pine. Forest Products Journal 40(1):11-14.

Martin, James W. 1984. Forest management practices that will influence product characteristics of the changing wood resource. pp. 115-123. In: Kellison, R. C., ed. Proceedings of symposium on utilization of the changing wood resource in the southern United States; 1984 June 12-13; Raleigh. Raleigh, NC: North Carolina State University.

Matziris, D. I.; Zobel, B. J. 1973. Inheritance and correlations of juvenile characteristics in loblolly pine *(Pinus taeda* L.). Silvae Genetica 22 (1/2): 38-45.

Megraw, R. A. 1985. Wood quality factors in loblolly pine. Atlanta: TAPPI Press. 88 pp.

Paul, B. H. 1957. Juvenile wood in conifers. Rep. No. 2094. Maison, WI: U. S. Department of Agriculture, Forest Service, Forest Products Laboratory. 8 pp.

Pearson, R. G.; Gilmore, Robert C. 1980. Effect of fast growth rate on the mechanical properties of loblolly pine. Forest Products Journal 30(5):47-54.

Pearson, R. G. 1988. Compressive properties of clear and knotty loblolly pine juvenile wood. Forest Products Journal 38(7/8):15-22.

Schmidtling, Ronald C. 1973. Intensive culture increases growth without affecting wood quality of young southern pines. Canadian Journal of Forest Research 3:565-573.

Senft, John F.; Quanci, Martin J.; Bendtsen, B. Alan. 1986. Pro perty profile of 60-year old Douglas-fir. Proc. 47349 pp. 17- 28. In: Juvenile Wood: What does it mean to forest management and forest products?; 1985 October 17 and November 7. Portland, OR and Bellingham, WA. Madison, WI: Forest Products Research Society.

Taras, M. A. 1965. Some wood properties of slash pine *(Pinus ellioti* Engelm.) and their relationship to age and height-- within the stem. Raleigh, NC: North Carolina State University. Ph. D. dissertion.

Thomas, R. J. 1984. The characteristics of juvenile wood. pp. 40-52. In: Kellison, R. C. ed. Proceedings of symposium on utilization of the changing resource in the southern United States; 1984 June 12-13; Raleigh. Raleigh, NC: North Car olina State University.

Wareing, P. F. 1958. The physiology of cambial activity. Journal of Institute of Wood Science (1): 34-42.

Zahner, Robert. 1963. Internal moisture content stress and wood formation in conifers. Forest Products Journal (6) :240-247.

Zobel, B. J.; Talbert, J. T. 1984. Applied forest tree improvement. New York: John Wiley and Sons. 505 pp.

Zobel, Bruce. 1981. Wood quality from fast-grown plantations. TAPPI 64(1):71-74.

Zobel, R. J.; Jett, J. B.; Hutto, R. 1978. Improving wood density of short rotation southern pine. TAPPI 61(3):41-44.

Zobel, Bruce; Webb, Charles; Henson, Fay. 1959. Core of juvenile wood of loblolly and slash pine trees. TAPPI 42(5):345-355.

Zobel, Bruce; Blair, Roger. 1976. Wood and pulp properties of juvenile wood and topwood of the southern pines. Journal Applied Polymer Sciences (Applied Polymer Symposium) 28:421-433.

Zobel, Bruce J.; McElwee, Robert L. 1958. Natural variation in wood specific gravity of loblolly pine, and an analysis of contributing factors. TAPPI 41(4):158-161.

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